

Age and growth of king and Spanish mackerel larvae and juveniles from the Gulf of Mexico and U.S. South Atlantic Bight

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Synopsis

Sagittal otoliths from 50 king mackerel 2.9–13.0 mm SL and 72 Spanish mackerel 2.8–22.0 mm SL collected off the southeast U.S. were examined whole at 400× using a compound microscope-video system. Otoliths of both species had visible, presumably daily, growth increments as well as finer subdaily increments. Otolith growth was directly proportional to growth in standard length for king ($r^2 = 0.91$) and Spanish mackerel ($r^2 = 0.86$). Spanish mackerel were estimated to be 3–15 d old with a mean absolute growth rate (SL/number of growth increments) and 95% confidence interval of $1.15 \pm 0.07 \text{ mm} \cdot \text{d}^{-1}$. The least squares linear equation: $\text{SL} = -1.30 + 1.31 (\text{age in days})$, with $r^2 = 0.67$ and $p < 0.001$, described the relationship between length and age. There was a significant positive relationship between absolute growth rate and fish length. King mackerel were estimated to be 3–15 d old with a mean absolute growth rate of $0.89 \pm 0.06 \text{ mm} \cdot \text{d}^{-1}$. The least squares linear equation: $\text{SL} = 0.37 + 0.82 (\text{age in days})$, with $r^2 = 0.77$ and $p < 0.001$, best described the relationship between length and age. The relationship between growth rate and fish length was not significant. The growth rate of king mackerel was slightly higher for fish from the Mississippi River plume than from all other locations combined, while Spanish mackerel growth rates were not significantly different.

Introduction

King and Spanish mackerel, *Scomberomorus cavalla* and *S. maculatus*, are highly migratory, coastal members of the family Scombridae (Collette & Russo 1984). Both species are abundant off the southeastern U.S. and support large commercial and recreational fisheries (Manooch 1979).

Several studies have examined the age and

growth of the adults (i.e. \geq age one) of both species (Klima 1959, Beaumariage 1973, Powell 1975, Johnson et al. 1983, Fable et al. 1987, Manooch et al. 1987), while one study (Waltz 1985¹) dealt with larger juveniles 85–365 mm FL. The larvae and juveniles of several other scombrids have been aged, including bluefin, *Thunnus thynnus*, yellowfin, *T. albacares*, and skipjack tuna, *Katsuwonus pelamis*, as well as Atlantic and

¹ Waltz, W. 1985. Evaluation of a technique for estimating age of young-of-the-year king (*Scomberomorus cavalla*) and Spanish mackerel (*Scomberomorus maculatus*). S.C. Wildl. Mar. Res. Dep. MARMAP Rep. for contract number 6-35147.

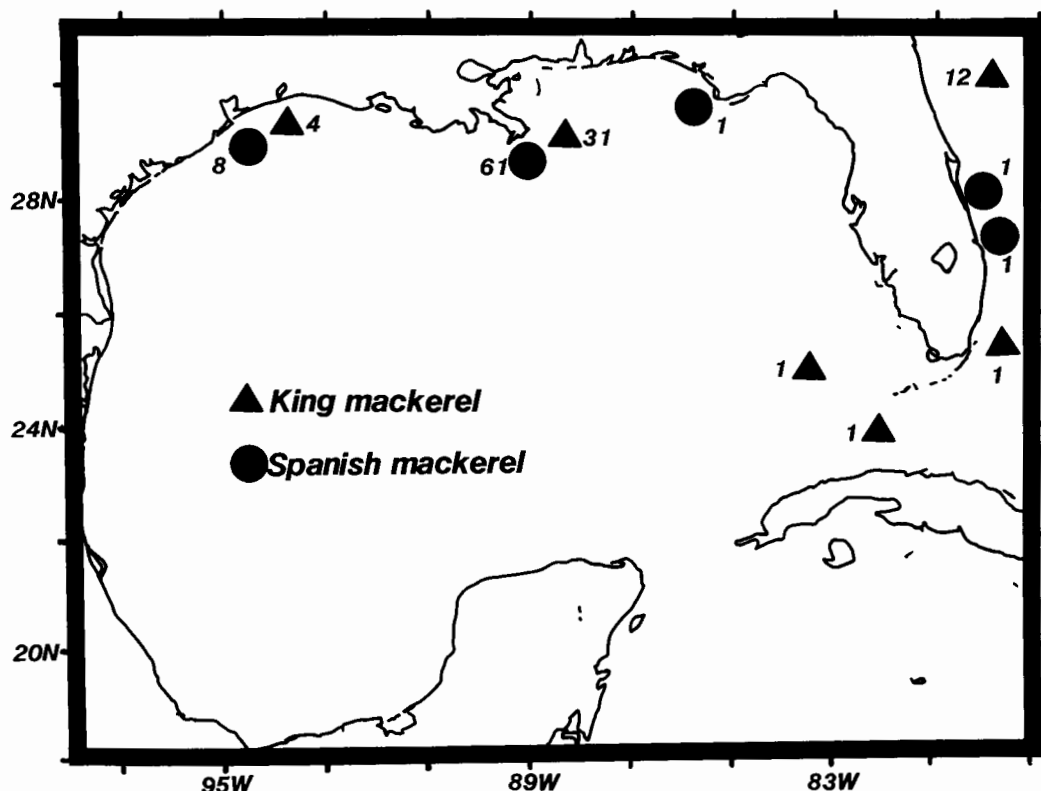


Fig. 1. Collection sites for king and Spanish mackerel in May and September 1986. Sample sizes are shown beside each sampling location.

chub mackerel, *Scomber scombrus* and *S. japonicus* (Kendall & Gordon 1981, Uchiyama & Struhsaker 1981, Brothers et al. 1983, and Radtke 1983). However, no published study has been directed at aging king or Spanish mackerel larvae or early juveniles.

The objectives of our study were to determine the feasibility of aging king and Spanish mackerel larvae and early juveniles using otoliths, calculate growth rates, and compare growth rates of fish collected in the Mississippi River plume with those from all other locations.

Materials and methods

King and Spanish mackerel 2.8–22.0 mm SL were

captured with 1 × 2 m, 0.947 mm mesh neuston and 61 cm, 0.333 mm mesh bongo nets in 1986 in the Gulf of Mexico and Atlantic Ocean from Galveston, Texas to Jacksonville, Florida (Fig. 1). All king mackerel were collected during 3–26 September; 49 of the Spanish mackerel were collected on 9 May and 23 during 4–26 September. Upon capture, fish were preserved in 95% ethanol for 24 h, after which the preservative was drained and fresh ethanol added.

Fish were measured to the nearest 0.1 mm SL using an ocular micrometer. The largest otoliths (sagittae) were removed by dissolving the entire fish, or just the head of larger individuals, on a glass slide with 5% NaOCl solution (bleach) (Epperly & Arenholz 1988²). Fish were left in bleach solution, within a covered dish, until the tissue

² Epperly, S.P. & D.W. Arenholz. 1988. Methods for preparing, sectioning, and polishing otoliths for daily ageing. Unpublished manuscript. Southeast Fisheries Center, Beaufort Laboratory, National Marine Fisheries Service, NOAA, Beaufort, NC 28516-9722.

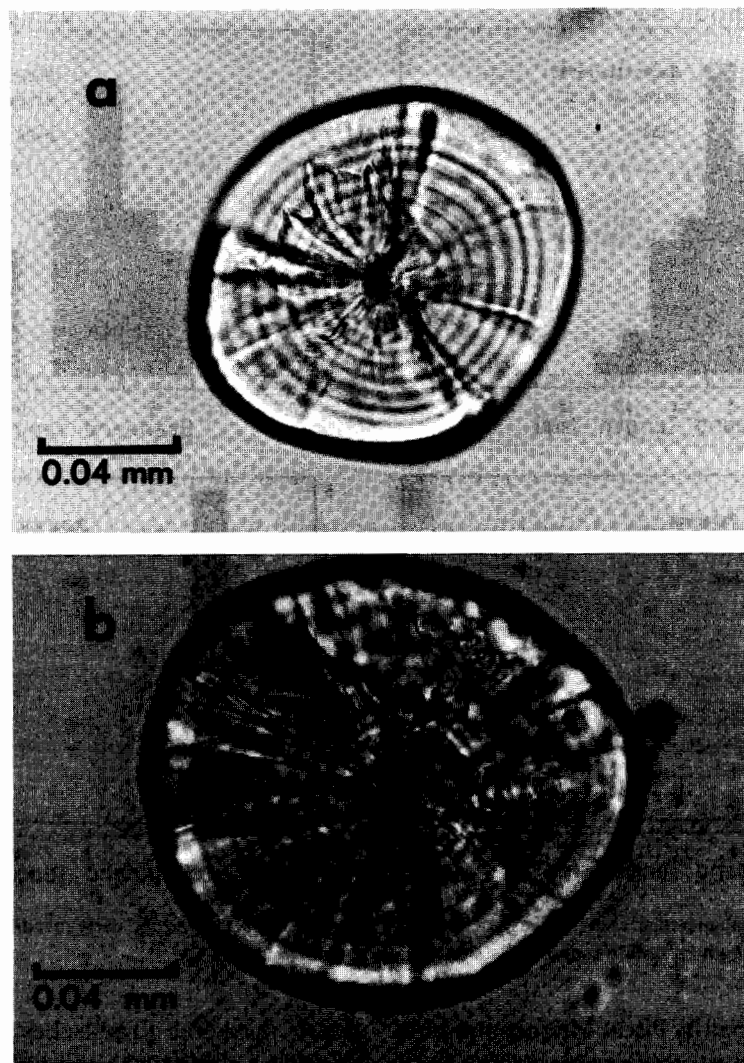


Fig. 2. Whole sagittal otoliths from a 9 d old, 5.7 mm SL king mackerel (a) and a 9 d old, 8.2 mm SL Spanish mackerel (b).

surrounding the otoliths dissolved (2–20 h). The otoliths were isolated using a dissecting microscope equipped with plane polarized light (12–50 \times). Otoliths, still on the original glass slide, were then washed with distilled water, dried, and mounted with FLO-TEXX³, a polymer mounting medium, on the original slide to eliminate the possibility of their loss. Polishing of the otoliths was not required for increment analysis. The otoliths were thin enough that only optical sectioning, i.e.

focusing to the plane of maximum clarity (Brothers et al. 1976), was necessary to obtain total ring counts.

Whole otoliths were examined under transmitted light at 400 \times using a compound microscope-video system. This system consisted of a MOS video camera mounted on a compound microscope, a 19 inch video monitor, a mouse, and a microcomputer. The video signal was digitized in a computer and then displayed on the monitor. This system,

³ Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

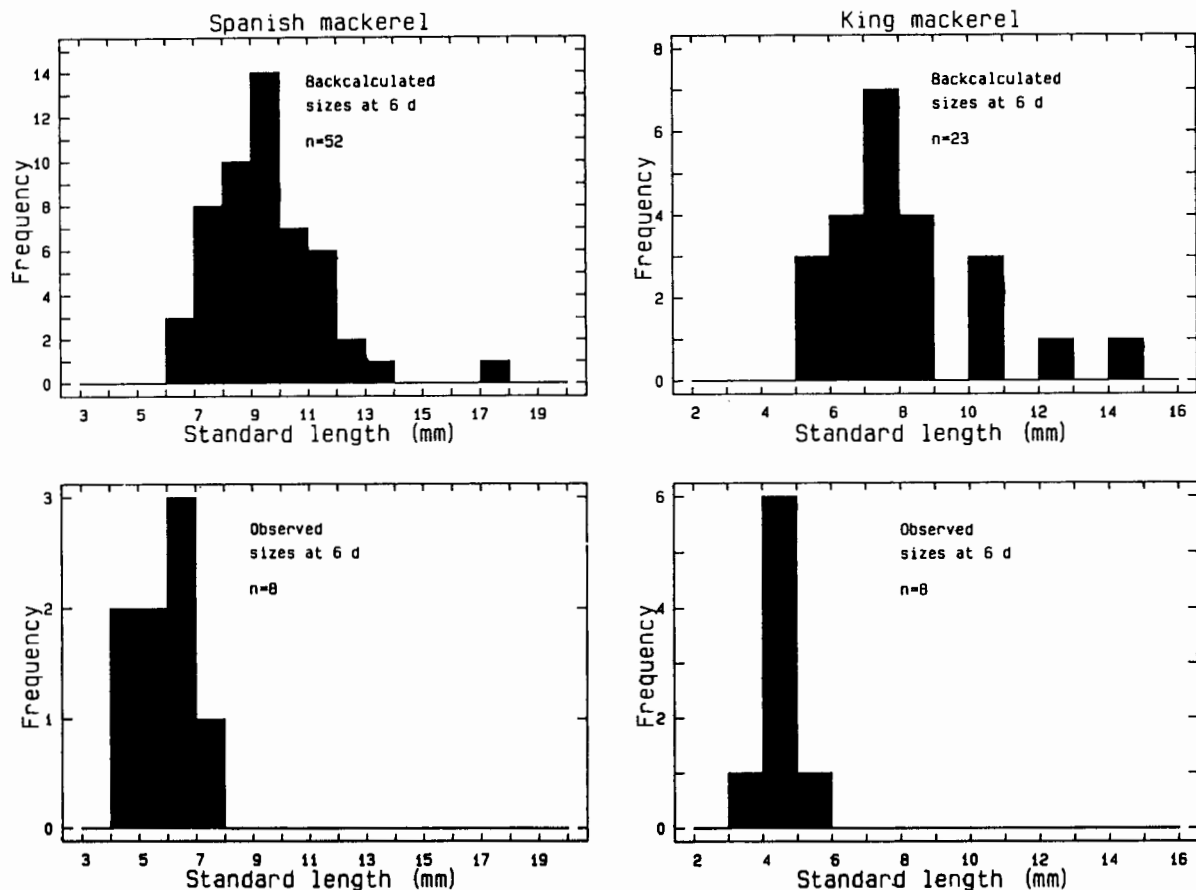


Fig. 3. Observed and backcalculated sizes at 6 d of age of Spanish and king mackerel larvae and early juveniles. Backcalculations were made using the standard length on otolith radius regression equation.

using software developed by Pisces Microcomputer Co., was used to measure otolith radii opposite the rostral region.

Increments were counted independently by three readers and the mean rounded to the nearest integer was used as the best estimate. When the three original counts differed by more than two rings, the otolith was reread by all three readers. If there was still disagreement after the second reading, the otolith was not included in the analysis. Otoliths damaged or obscured during mounting were considered unreadable and not aged.

We made no attempt to determine effects of shrinkage and adjust our results accordingly. Although shrinkage coefficients of 5–21% have been reported for clupeids (Blaxter 1971, Hay 1982) and engraulids (Theilacker 1980) and up to 15% for

chub mackerel (Theilacker & Dorsey 1980 in Brothers et al. 1983) as a result of capture by net and, in the latter case, formalin fixation, we concluded that it was reasonable to ignore shrinkage effects when estimating growth rates.

Results

Sagittal otoliths of king and Spanish mackerel larvae have visible, presumably daily, growth increments as well as finer subdaily increments (Fig. 2). Brothers et al. (1983) defined these increments as bipartite structures composed of one optically transparent and one less transparent layer. Typically, the first three to six growth increments were closely spaced and fairly distinct with the remaining

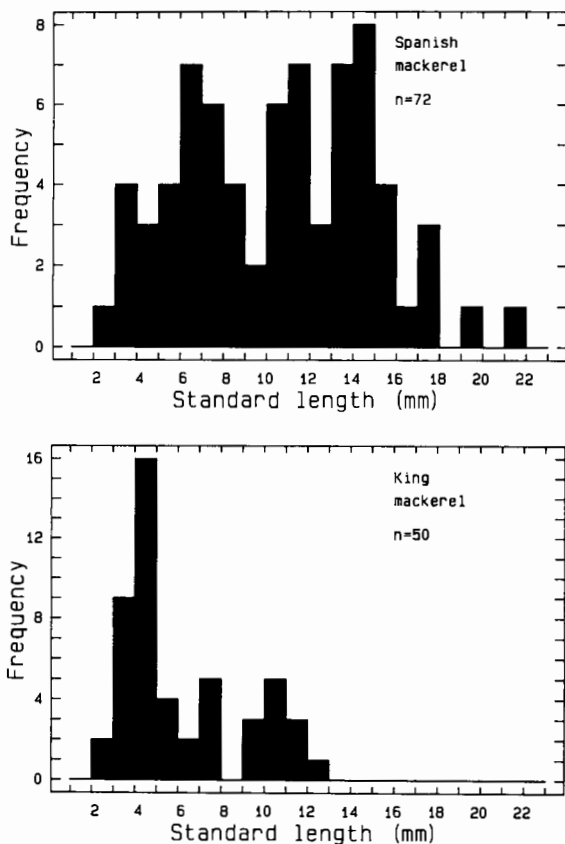


Fig. 4. Length frequency distribution of aged Spanish and king mackerel collected in 1986.

ones considerably wider apart and often harder to distinguish. Most of the otoliths of both species had some narrower, less distinct subdaily marks visible at $400\times$, although they were much more visible at $1000\times$.

We could not directly establish the diel periodicity of the marks on the otoliths. However, we assumed, like Brothers et al. (1983), that the growth increments we counted were 'structural homologues of features demonstrated to be formed with diel periodicity in a wide variety of species, particularly in other scombrids' (many studies cited in Brothers et al. 1983). We attempted to dipnet mackerel larvae in hopes of marking them with tetracycline and directly validating our aging method. Unfortunately, we caught no king mackerel and most of the 20 or so Spanish mackerel captured

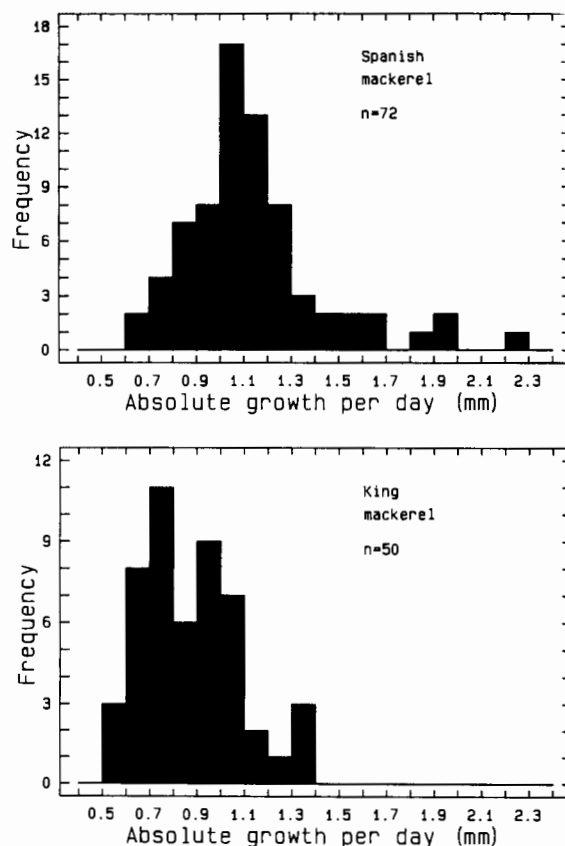


Fig. 5. Frequency distribution of growth rates for Spanish and king mackerel larvae and early juveniles.

died within 2–3 h, although one lived about 15 h and another about 48–60 h.

Some evidence for the timing of ring deposition is provided by the fact that otolith radius opposite the rostrum (OR) was directly proportional to standard length for king and Spanish mackerel larvae and early juveniles. Least squares linear regression yielded the following equations for the two respective species.

$$SL = 1.96 + 0.015(OR), r^2 = 0.91, p < 0.001, n = 50 \text{ and}$$

$$SL = 2.66 + 0.017(OR), r^2 = 0.86, p < 0.001, n = 72.$$

These highly significant relationships, although not validation in the strict sense, demonstrate that fish growth and otolith growth are proportional and therefore are consistent with the hypothesis that the increments are formed daily.

As additional validation evidence we compared the frequency distributions of observed and backcalculated sizes at the sixth increment (Fig. 3). Backcalculated sizes, calculated using the above regressions of SL on otolith radius, showed a distinct mode, suggesting there was a regular, consistent pattern to increment formation. There was reasonable agreement between observed and backcalculated sizes, however backcalculated modal sizes were 2–3 mm larger than observed modal sizes. This difference can reasonably be explained by size-selective mortality on slower growing fish as Post & Prankevicius (1987) found in yellow perch.

We were more successful at aging king than Spanish mackerel. Out of 81 readable Spanish and 50 readable king mackerel otoliths, 9 (11%) of the former were excluded from the analysis because readers could not agree on their ages.

The Spanish mackerel in our study were 2.8–22.0 mm SL and 3–15 days old (Fig. 4). Mean absolute growth rate (SL/number of growth increments) and 95% confidence interval was $1.15 \pm 0.07 \text{ mm} \cdot \text{d}^{-1}$, with a range of $0.64\text{--}2.26 \text{ mm} \cdot \text{d}^{-1}$ (Fig. 5). A least squares linear regression of standard length in mm on age in days yielded the equation: $\text{SL (mm)} = -1.30 + 1.31 (\text{age in days})$, $r^2 = 0.67$ and $p < 0.001$ (Fig. 6). The slope of this equation, 1.31, provides another estimate of average absolute growth per day over the size range sampled. We found a significant positive relationship between growth per day and fish length ($r^2 = 0.54$, $p < 0.001$), indicating that absolute growth rate increases with age.

King mackerel we aged ranged from 2.9 to 13.0 mm SL and were 3–15 days old (Fig. 4). Mean absolute growth per day and 95% confidence interval was $0.89 \pm 0.06 \text{ mm}$, with a range of $0.54\text{--}1.33 \text{ mm}$ (Fig. 5). For king mackerel, the least squares linear regression model of growth: $\text{SL} = 0.37 + 0.82 (\text{age in days})$, explained 77% of the variation in SL with age at $p < 0.001$ (Fig. 6). This species showed a slightly positive, and nonsignificant, relationship between absolute growth per day and fish size over the narrow, 3–15 mm SL, size range aged.

The absolute growth rate of king mackerel from the Mississippi River plume was slightly higher

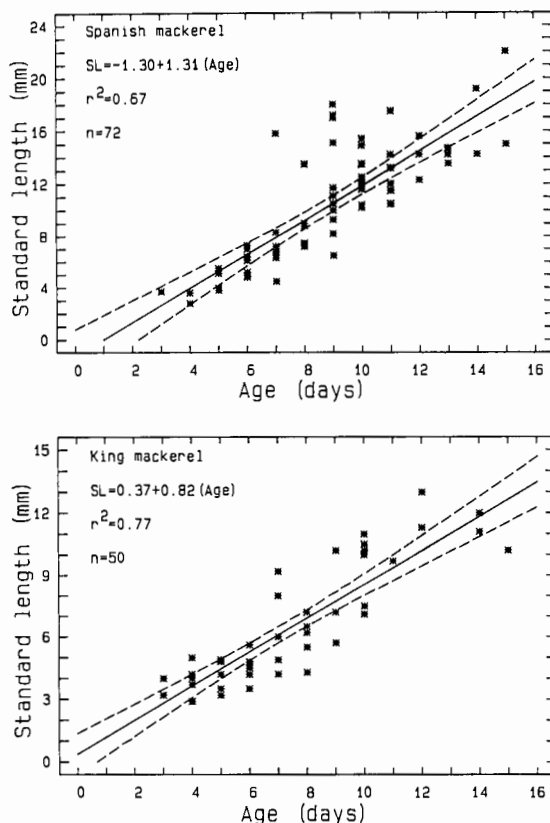


Fig. 6. Linear relationships between standard length (SL) and daily age with 95% confidence limits for Spanish and king mackerel larvae and early juveniles.

than that of fish collected at all other locations. Mean absolute growth rate was $0.95 \pm 0.07 \text{ mm} \cdot \text{d}^{-1}$ ($n = 31$) for king mackerel from the Mississippi River plume and $0.79 \pm 0.09 \text{ mm} \cdot \text{d}^{-1}$ ($n = 19$) for fish from all other locations combined. ANCOVA of absolute growth rate, with fish size (SL) as the covariate and location in relation to the Mississippi plume as the main effect, showed that these differences were significant (Table 1). Fish size was included in the covariance model to compensate for differences in size ranges of the fish from plume and nonplume areas, as well as changes in absolute growth with size. Both ocean of origin ($n = 13$ for the Atlantic, $n = 37$ for the Gulf) and location were included as main effects in the initial ANCOVA; the former was not significant and was therefore dropped from the final model.

Spanish mackerel growth was similar in all areas.

ANCOVA of absolute growth rate, with fish size as the covariate and location (plume vs. nonplume) and month of capture as main effects, indicated no significant differences. Month was included as an important source of variance in growth because 49 fish were collected in May from one station in the plume and 23 were caught in September.

Mean absolute growth rate was not significantly different between Spanish and king mackerel. ANCOVA of absolute growth rate, with standard length as a covariate and species as the main effect, showed no significant difference.

Discussion

There is support in the literature for our contention that growth increments are deposited daily. The visible, presumed daily and subdaily, growth increments we observed in larval and early juvenile (2.8–22.0 mm SL) king and Spanish mackerel otoliths were also noted in otoliths from 111–290 mm FL king and 82–365 mm FL Spanish mackerel by Waltz (1985'), who called them major and minor rings. Daily growth increments have been validated in at least three scombrids, including chub

mackerel (Brothers et al. 1983), and skipjack and yellowfin tuna (Uchiyama & Struhsaker 1981, Radtke 1983). Daily increments have also been noted, but not directly validated, in bluefin tuna (Brothers et al. 1983) and Atlantic mackerel (Kendall & Gordon 1981).

The difficulty of obtaining, as well as holding and rearing, king and Spanish mackerel larvae and early juveniles has been a major impediment to directly validating daily growth increments. Grimes et al. (1989) found records of only 1384 king mackerel larvae and early juveniles from the entire Gulf of Mexico through 1986. Clemens (1956) attempted to hold 14 dipnetted sierra mackerel, *Scomberomorus sierra*, 12–22 mm SL, but only two lived as long as 13 days; all others died within a few days of capture.

Growth increment formation apparently begins at a very young age in king and Spanish mackerel, so any aging error resulting from a delay in formation of the first increment would be very small. Our growth equations predict that at age 2 days king mackerel are 2.01 mm SL and Spanish mackerel are 1.32 mm SL. Both these values are very close to reported sizes at hatching and smallest sizes collected. Mackerel embryos hatch in about 24 h (Ryder

Table 1. Analysis of covariance of absolute growth per day (standard length/number of growth increments) for king mackerel 2.9–13.0 mm SL, Spanish mackerel 2.8–22.0 mm SL, and between the two species.

Species	Source of variation	Sum of squares	df	Mean square	F	Sig. level
King mackerel	Covariate standard length	0.1213	1	0.1213	3.50	0.068
	Main effect					
	Location in relation to Mississippi River plume	0.2008	1	0.2008	5.79	0.020
	Residual error	1.6305	47	0.0347		
	Total (corrected)	1.9526	49			
Spanish mackerel	Covariate standard length	3.5346	1	3.5346	86.76	0.000
	Main effects	0.2233		0.1116	2.74	0.072
	Location in relation to Mississippi River plume	0.0269	1	0.0269	0.66	0.428
	Month of capture	0.0561	1	0.0561	1.38	0.245
	Residual error	2.7703	68	0.0407		
	Total (corrected)	6.5282	71			
	Covariate standard length	5.2272	1	5.2272	120.37	0.000
	Main effect species	0.1267	1	0.1267	2.92	0.090
	Residual error	5.1676	119	0.0434		
	Total (corrected)	10.5216	121			

1882, Stewart 1983). King mackerel reared from eggs were 2.4 mm NL at hatching (Mayo 1973), while Spanish mackerel were about 2.2 mm SL (estimated from Ryder 1882 by Dwinell & Futch 1973). McEachran et al. (1980) collected both species as small as 1.8 mm SL off Texas, and Burns (1981) found king mackerel as small as 2.5 mm SL off southeast Florida.

Early increment formation has been found in other scombrids as well. Captive skipjack tuna began forming increments 1 d after hatching and 4 d after spawning (Radkte 1983), and captive chub mackerel also formed their first increment 3–4 d after hatching (Brothers, unpublished MS in Brothers et al. 1983).

Our growth rates for Spanish (1.15 and $1.31 \text{ mm} \cdot \text{d}^{-1}$) and king mackerel (0.89 and $0.82 \text{ mm} \cdot \text{d}^{-1}$) are similar to most growth data in the literature for other scombrid larvae or juveniles, e.g., bluefin tuna ($1.39 \text{ mm} \cdot \text{d}^{-1}$) (Brothers et al. 1983), skipjack tuna ($1.6 \text{ mm} \cdot \text{d}^{-1}$ up to 27 cm FL) and yellowfin tuna ($1.4 \text{ mm} \cdot \text{d}^{-1}$ up to 64.2 cm FL) (Uchiyama & Struhsaker 1981) and Atlantic mackerel ($1.3 \text{ mm} \cdot \text{d}^{-1}$) (calculated by Waltz 1985¹ using equation in Kendall & Gordon 1981).

Our absolute growth rates (0.82 – $0.89 \text{ mm} \cdot \text{d}^{-1}$) for 2.9–13 mm SL king mackerel are lower than Waltz's (1986⁴) (2.4 – $2.8 \text{ mm} \cdot \text{d}^{-1}$) for fish 111–290 mm FL. Waltz's higher absolute rate for larger king mackerel is to be expected, and is the typical pattern during the early life history of young fishes when absolute growth increases and relative growth decreases.

Relative growth rate, which ranged from 6 to 32% of fish length in our 2.9–13 mm SL fish, was only 1 to 3% in Waltz's 111–290 mm FL fish. The significant positive relationship we found between growth per day and fish length in Spanish mackerel is further evidence of this increase in absolute growth rate with size. The absence of this relationship in king mackerel in our study is probably an

artifact of the narrow, 2.9–13 mm SL, size range of the data.

The slightly higher growth rate of king mackerel from the Mississippi plume area may be related to greater food availability there. King mackerel larvae and juveniles are almost totally piscivorous from a very small size (~ 2.5 mm SL) Finucane et al. 1988⁵), and Grimes & Finucane (unpublished data) found much higher concentrations of ichthyoplankton (potential prey for young mackerel) in Mississippi River plume frontal waters than in adjacent shelf and plume waters during late summer. Also, young mackerels were mostly associated with frontal waters.

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⁴ Waltz, W. 1986. Data report on preliminary attempts to assess and monitor size, age, and reproductive status of king mackerel in the South Atlantic Bight. S.C. Wildl. Mar. Res. Dep. MARMAP Rep. for contract number 6–35147.

⁵ Finucane, J.H., C.B. Grimes & S.P. Naughton. 1988. Diet and feeding ecology of young king mackerel and Spanish mackerel. Unpublished manuscript. Southeast Fisheries Center Panama City Laboratory, National Marine Fisheries Service, NOAA, 3500 Delwood Beach Road, Panama City, FL 32407.

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